Safety Impacts of Roundabouts on Bicycles and Pedestrians

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Contents

Abstract ......................................................................................................................................................... 2
Introduction .................................................................................................................................................. 3
Modern Roundabout Design Guidelines ................................................................................................... 3
Dangerous Intersections ............................................................................................................................. 4
    Table 1: US Traffic Fatalities in 2010 (IIHS 2010) .................................................................................. 5
Roundabouts Increase Safety ...................................................................................................................... 5
Review of Existing Literature ........................................................................................................................ 6
Results and Discussion ................................................................................................................................ 10
    Table 2: Aggregated Safety Impacts of Roundabouts on Cyclists and Pedestrians ......................... 10
    Table 3: Fraction of Cyclists in Roundabout Crashes as a Percentage of All Traffic ...................... 11
Analysis ................................................................................................................................................... 12
Conclusion ................................................................................................................................................... 14
Works Cited ................................................................................................................................................. 16

<table>
<thead>
<tr>
<th>Table 1: US Traffic Fatalities in 2010 (IIHS 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
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<tr>
<td>2010</td>
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<table>
<thead>
<tr>
<th>Table 2: Aggregated Safety Impacts of Roundabouts on Cyclists and Pedestrians</th>
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<td>Improved Safety</td>
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<tr>
<th>Table 3: Fraction of Cyclists in Roundabout Crashes as a Percentage of All Traffic</th>
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<tbody>
<tr>
<td>Percentage</td>
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<tr>
<td>-----------------------------------</td>
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<tr>
<td>Roundabout Crashes</td>
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<tr>
<td>Non-Roundabout Crashes</td>
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Abstract
Numerous studies point to the effectiveness of roundabouts reducing fatal collisions among vehicles at intersections. However, the impact on vulnerable road users (i.e. pedestrians and bicyclists) is less clear. Historic data from numerous countries was compiled and analyzed through the lens of safety on pedestrians and cyclists. A weighted average was applied to changes in injury crashes in order to identify trends in safety impacts. It was determined that roundabouts demonstrate a generally positive trend on pedestrian safety, reducing injury crashes by an aggregated 50%. The results of bicycle injury crashes were more mixed, with no clear trend emerging. Various issues regarding cyclists’ interface with roundabouts and roundabout design were explored. It was concluded that safety for cyclist users is maximized through the reduction of speeds, mixed flow as opposed to lane segregation of cyclists, minimization of lane counts, and minimization of traffic volumes when possible.
Introduction

Modern Roundabout Design Guidelines

The modern roundabout is a passive form of intersection control in which a generally circular obstruction in the middle of an intersection forces traffic to circulate in a single direction. Modern roundabouts are distinct from their historic origin, the traffic circle/rotary, in that their diameters tend to be much smaller and traffic on the approach yields to circulating traffic.

Per the USFHWA, roundabout design should incorporate the following elements to maximize safety (US Federal Highway Administration, 2000):

- Pedestrian Crossing should be at least one car length beyond inscribed diameter, usually with a pedestrian refuge in the splitter island
- No bike lanes within roundabout
- Smaller diameters lead to lower speeds
- Lower speeds lead to higher safety
- Single lane roundabouts are safer than multi-lane

Mini-roundabouts can also be a desirable design option on local, low volume roads where geometry and/or budget constrains a full-sized roundabout.

**Dangerous Intersections**

Perhaps the most common reason to install roundabouts is safety. According to a survey conducted of among transportation agencies in nine US states of 38 roundabouts, greater safety was the reason for the installation of a roundabout (NCHRP, 1998).

Concern for safety is well-founded. The Insurance Institute for Highway Safety lists the following traffic fatality for 2010:
Table 1: US Traffic Fatalities in 2010 (IIHS 2010)

<table>
<thead>
<tr>
<th></th>
<th>Passengers</th>
<th>Pedestrians</th>
<th>Motorcyclists</th>
<th>Bicyclists</th>
<th>Large truck occupants</th>
<th>Other</th>
<th>All motor vehicle deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large truck occupants</td>
<td>22,263</td>
<td>68%</td>
<td>4,280</td>
<td>13%</td>
<td>4,309</td>
<td>13%</td>
<td>474</td>
</tr>
</tbody>
</table>

Of most striking note regarding these statistics is how relatively dangerous it is to walk, bike, or ride a motorcycle given these share’s minuscule VMT relative to passenger vehicles.

Indeed intersections are dangerous places. In 2009, intersections accounted for 2.21 million crashes, almost 25% of all traffic fatalities (6,770 fatal crashes), and almost 50% of all traffic injuries. In this same year, 1,063 pedestrians were killed at or near intersections, with 521 (over half) at signalized intersections (National Highway Traffic Safety Administration, 2009). Without a doubt, implementation of roundabouts reduces the severity of crashes compared to signalized intersections. For example, Persaud et al found examined 24 roundabouts in a variety of US settings and found that total crashes were reduced by 39% and injury crashes by 76% (Bhagwant N. Persaud, 2000).

Roundabouts Increase Safety

Roundabouts improve vehicle safety in at least three ways. First, approaching vehicles are forced to reduce their speed in order to accommodate the deflection angle at the yield line and inscribed diameter. This is in contrast to traffic circles, whose large diameters and priority to entering traffic encourage high speeds. Second, when collisions do occur, they are at oblique rather than perpendicular angles, reducing crash energies. Third, roundabouts have fewer conflict points than equivalent perpendicular intersections, as exhibited by Figure 4.
Review of Existing Literature

In order to identify trends on safety impacts of roundabouts on vulnerable users, a thorough literature review was conducted:


Evaluates before and after traffic safety performance of 24 roundabouts over 8 US states. Includes urban, suburban, and rural settings. Finds a total crash reduction of 39% and an injury crash reduction of ~90%.


Looks at safety effects of roundabouts built in Flanders region of Belgium from 1994 to 2000. Found 39% overall reduction in injury accidents, but injury increases at high speed intersections that were previously signalized. Injury accidents increased 28% at 50 km/h x 50 km/h for vulnerable users. Vulnerable road users are defined as pedestrians, cyclists, moped drivers, and motorcyclists.

Analysis of all crashes in roundabouts in the Australian state of Victoria between 2005 and 2009. Determined entering car striking circulating cyclist accounted for 82% of bike-auto collisions. Includes marking prescriptions.


Looks at the safety effects of converting 28 signalized intersections to roundabouts in the Indiana and North Carolina. Finds reductions in both total and injury crashes. Does not break out data by mode. Includes Suburban, Urban, one and two-lane, and three and four-approach roundabouts. Finds safety benefits decrease a traffic volumes increase.


Study of 171 bicycle crashes on Danish island of Funen. Analyzed various geometric features, age and traffic volume in 88 roundabouts.


Reviews roundabout crashes in Belgium, Denmark, and Sweden. Identifies entering car/circulating bicyclist as the most common accident. Discusses safety attributes of mixed-flow vs. separated (i.e. pedestrian) crossings. Also discusses successes and failures of various marking strategies.

Survey using structured interviews conducted in five Danish roundabouts (N=1,019).
Conclusion: Cyclists prefer road designs with a clear regulation of road user behavior; need to increase user knowledge of traffic rules.


Provides safety statistics for intersection crashes.


Explores safety performance of roundabouts via regression model and ANOVA model. Reviews design elements. Examines human behavior within roundabouts using video data.

NCHRP. (2010). *REPORT 672*. Transportation Research Board.

Most comprehensive report on roundabout design and traffic safety data to date. Global comparisons made. Makes recommendations on design, markings, and behavior of users within roundabouts.


Study involving cyclist accidents at 91 roundabouts in Flanders region of Belgium. Safety decreased.

90 roundabouts analyzed in Flanders, Belgium. Finds that roundabouts with cycle lanes perform significantly worse than other design types like mixed traffic, separate cycle paths, and grade-separated cycle paths.


90 roundabouts results in Flanders, Belgium. Vulnerable road users are more frequently than expected involved in crashes at roundabouts. Roundabouts with cycle lanes perform significantly less than roundabouts with cycle paths. Finds “safety in numbers” for cyclists and moped riders in roundabouts, less certain about pedestrians.


US-accepted engineering standard for signage and markings for road design.


Brief guideline of acceptable design and technical aspects of roundabouts. Considers need of motorists, bicycles, pedestrians, and emergency vehicles.


Older but much more comprehensive design guide. Will be used to determine whether the USFHWA has learned anything in 10 years.
Results and Discussion

Most safety studies do not disaggregate casualties by mode, greatly reducing the amount of data which can answer the research question. Europe has far more roundabouts than North America, therefore most of the detailed study locations are northern European. Since methodologies among studies differ, side-by-side comparisons must be viewed critically. Nevertheless, in an attempt to identify overall trends, the safety performance of studies which gathered bicycle and pedestrian injury crashes were analyzed. Weighted averages were obtained by summing the percent increase or decrease in crashes relative to the sample size.

Table 2: Aggregated Safety Impacts of Roundabouts on Cyclists and Pedestrians

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Study Location</th>
<th>Cyclist Increase or Decrease in Injury crashes</th>
<th>Number of Roundabouts Studied</th>
<th>Pedestrian Increase or Decrease in Injury crashes</th>
<th>Number of Roundabouts Studied</th>
</tr>
</thead>
<tbody>
<tr>
<td>De Habaeder &amp; Vereeck</td>
<td>2007</td>
<td>Belgium</td>
<td>28%</td>
<td>95</td>
<td>28%</td>
<td>95</td>
</tr>
<tr>
<td>Dinis et al</td>
<td>2008</td>
<td>Belgium</td>
<td>27%</td>
<td>91</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Koelle &amp; Guichet</td>
<td>1991</td>
<td>France</td>
<td>16%</td>
<td>179</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Schoon &amp; van Minnen</td>
<td>1993</td>
<td>Netherlands</td>
<td>-30%</td>
<td>181</td>
<td>-89%</td>
<td>181</td>
</tr>
<tr>
<td>Nyden &amp; Vosbein</td>
<td>2000</td>
<td>Sweden</td>
<td>-60%</td>
<td>21</td>
<td>-80%</td>
<td>21</td>
</tr>
<tr>
<td>Brude &amp; Larsson (Single Lane)</td>
<td>2000</td>
<td>Sweden</td>
<td>-21%</td>
<td>48</td>
<td>-79%</td>
<td>48</td>
</tr>
<tr>
<td>Brude &amp; Larsson (Multi Lane)</td>
<td>2000</td>
<td>Sweden</td>
<td>112%</td>
<td>24</td>
<td>12%</td>
<td>24</td>
</tr>
<tr>
<td>NCHRP Report 264</td>
<td>1997</td>
<td>USA</td>
<td>-74%</td>
<td>11</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Stone et al</td>
<td>2002</td>
<td>USA</td>
<td>--</td>
<td>--</td>
<td>-7%</td>
<td>1</td>
</tr>
</tbody>
</table>

Weighted Average: 3% Cyclist, -50% Pedestrian

1Does not disaggregate "vulnerable" road users
2Does not disaggregate among two-revealed vehicles
3Assumes two-thirds single lane 1/3 multiline distribution
Additionally, certain studies gathered data on the fraction of cyclists involved in crashes as a percentage of all crashes. It is clear that while bicycles make up a small fraction of total vehicle traffic, they make a disproportionately high share of roundabout crashes.

The data suggests that while roundabouts are indeed safer when viewed in aggregate, and almost certainly is safer for pedestrians, the safety benefits are less clear for bicycles. Why is this so and what can be done to improve safety for cyclists?

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Location</th>
<th>Cyclists as Share of Total Volume</th>
<th>Cyclists as Share of Multi-Vehicle Crashes in Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cummings</td>
<td>2012</td>
<td>Australia</td>
<td>4%</td>
<td>24%</td>
</tr>
<tr>
<td>Daniels et al</td>
<td>2010</td>
<td>Belgium</td>
<td>4%</td>
<td>36%</td>
</tr>
<tr>
<td>Maycock &amp; Hall</td>
<td>1984</td>
<td>UK</td>
<td>N/A</td>
<td>15%</td>
</tr>
<tr>
<td>NCHRP Report 572</td>
<td>2007</td>
<td>USA</td>
<td>N/A</td>
<td>1%</td>
</tr>
<tr>
<td>Jørgensen &amp; Jørgensen</td>
<td>1994</td>
<td>Denmark</td>
<td>N/A</td>
<td>70%</td>
</tr>
</tbody>
</table>

Table 3: Fraction of Cyclists in Roundabout Crashes as a Percentage of All Traffic
Analysis

Saksuahg et al examined the inlet and outlet speed distributions of vehicles and bicycles on roundabout approaches, and concluded that regardless of the crossing method of cyclists, the differential in speed remained high.

Cummings noted that roundabout design varies by country. Certain northern European countries favor a radial, non-flared design, while other countries (including the US) favor tangential, flared entries and exits.

Numerous studies (Cummings 2012, Hels & Orozova-Bekkevold 2007) point to Entering Vehicle striking Circulating Cyclist as most common form of cyclist collision. This type of collision is referred to as the “looked, but did not see” type. It likely occurs as a result of cyclists’ tendency to remain in the edge of the outer lane (Lisa Sakshaug, 2009), during which they spend significant time on the edge of the approaching drivers’ sight lines. Figure 7 illustrates this phenomenon.
All literature suggests that cyclists should avoid the outer approximate 1.5 meters. Cyclists should instead circulate in traffic a’ la motorized-sized vehicle or dismount and use pedestrian crossings. Cummings went further in recommending extensive markings in order warn drivers of merging cycle traffic, and the encouragement of full lane occupation of cyclists through roundabouts.

Given high traffic volumes, appropriate context, and a sufficient budget, grade separation of non-motorized vehicles may be feasible (although most US documents make little or no mention of this step). Figure 9 shows an example of a cable-stayed pedestrian and cycle bridge which applies roundabout circulation rules.
Conclusion

While it is difficult to draw any concrete conclusions based on the comparison of existing studies outlined above, several statements can be made:

- With a slightly positive (3%) weighted average of studies, cyclists in roundabouts are likely to experience greater risk of injury in comparison to signalized intersections.
- Bicycles should never have dedicated lanes within the roundabout; rather bicycles should merge with traffic well before entering the roundabout, and circulate in the same manner as motorized vehicles, or dismount and cross at the pedestrian crossing.
- In cases of very high traffic volumes, grade separations for non-motorized traffic may be a reasonable solution.
- Pedestrians likely to experience lower risk of injury vs. signalized intersections, with a weighted average showing roughly 50% fewer injury accidents.
- Regarding safety for all modes, as traffic volumes increase, safety decreases.
• Increasing lane counts increases the number of conflict points and impairs sight lines, reducing safety for all users
• Increasing the deflection angle increases aggregated safety statistics
Works Cited


NCHRP. (2010). *REPORT 672*. Transportation Research Board.


